NASA-OU CREST 1.6c README

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(Draft version)

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1. A Brief Description of the Model

The **C**oupled **R**outing and **E**xcess **ST**orage (CREST) distributed hydrological model is a hybrid modeling strategy that was recently developed by the University of Oklahoma (http://hydro.ou.edu) and NASA SERVIR Project Team (www.servir.net). CREST simulates the spatiotemporal variation of water and energy fluxes and storages on a regular grid with the grid cell resolution being user-defined, thereby enabling global- and regional-scale applications. The scalability of CREST simulations is accomplished through sub-grid scale representation of soil moisture storage capacity (using a variable infiltration curve) and runoff generation processes (using linear reservoirs). The CREST model was initially developed to provide online global flood predictions with relatively coarse resolution, but it is also applicable at small scales, such as single basins. This README file and the accompanying code concentrates on and tests the model at the small scale. The CREST Model can be forced by gridded potential evapotranspiration and precipitation datasets such as, satellite-based precipitation estimates, gridded rain gauge observations, remote sensing platforms such as weather radar, and quantitative precipitation forecasts from numerical weather prediction models. The representation of the primary water fluxes such as infiltration and routing are closely related to the spatially variable land surface characteristics (i.e., vegetation, soil type, and topography). The runoff generation component and routing scheme are coupled, thus providing realistic interactions between atmospheric, land surface, and subsurface water.

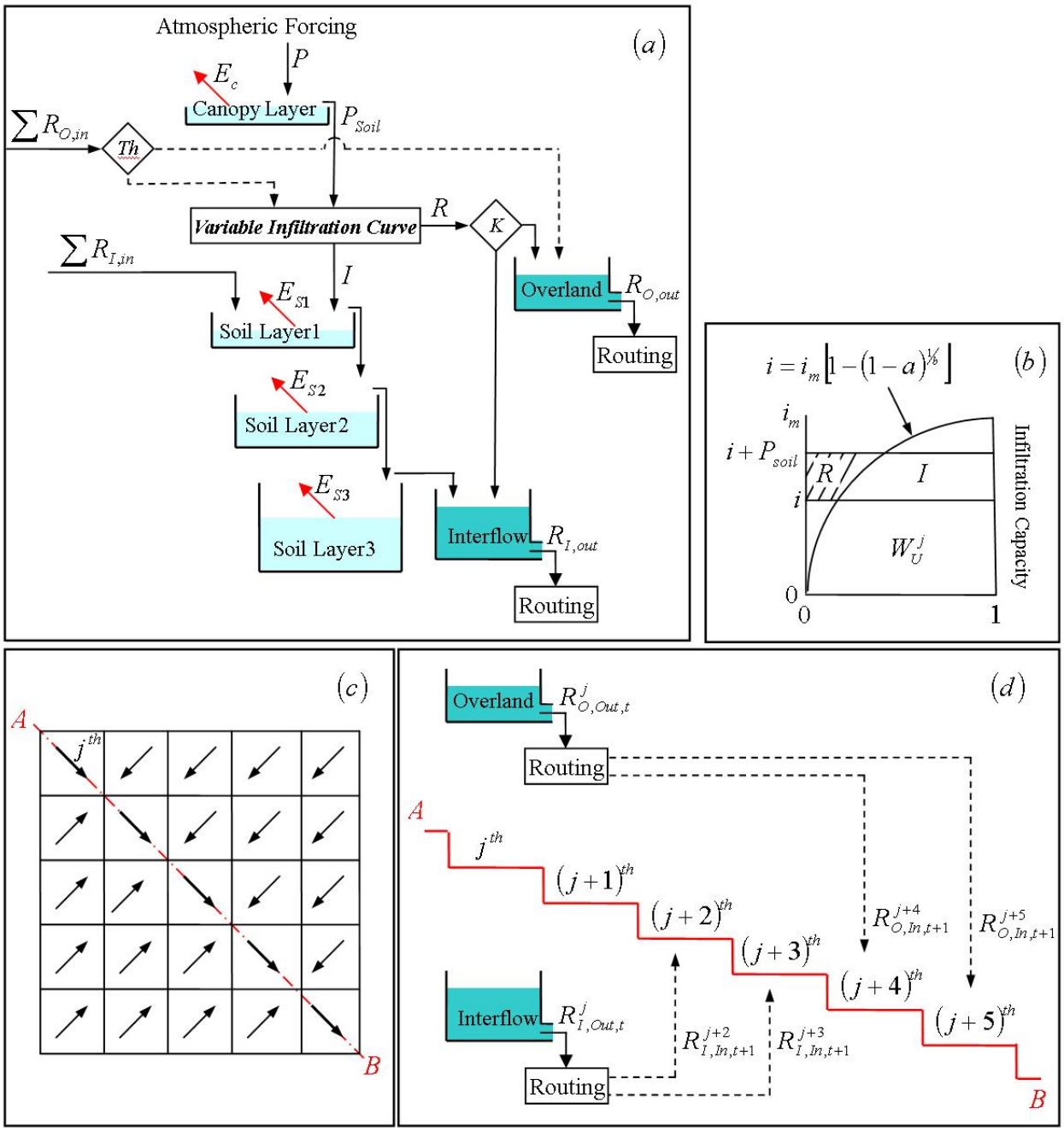

Fig. 1. Core components of the CREST model: (a) vertical profile of a cell including rainfall-runoff generation, evapotranspiration, sub-grid cell routing and feedbacks from routing; (b) variable infiltration curve of a cell; (c) plan view of cells and flow directions; and (d) vertical profile along several cells including sub-grid cell routing, downstream routing, and subsurface runoff redistribution from a cell to its downstream cells.

2. Compiling on Linux

It is not necessary to modify the source code of CREST in order to change settings or basins. The control file with a default name of “control.txt” and basic grids dictate the necessary settings for running the model. The control file name must be in lower case, other wise it may not be recognized on Linux/Unix operating systems.

2.1 Using “ifort” compiler

Compiling CREST is easy with any Fortran compiler. The source code to CREST is contained within a single file for ease of use. As such, in order to compile CREST using ifort all that is needed is a simple command such as "**ifort -o crest –assume byterecl -fpp crest1.6.f90**" this will compile the CREST Fortran source code file into an executable named "crest." The Intel Fortran compiler has many other command line arguments to enable additional optimizations and other features. For a full list and description of how to use them consult the Intel Fortran compiler manual.

2.2 Using “gfortran” compiler

The source code to CREST is contained within a single file for ease of use. As such, in order to compile CREST using gfortran all that is needed is a simple command such as **“gfortran -x f95-cpp-input -o crest -ffree-line-length-none -O3 crest1.6.f90”** this will compile the CREST Fortran source code file into an executable named "crest." The gfortran compiler has many other command line arguments to enable additional optimizations and other features. For a full list and description of how to use them consult the gfortran compiler manual.

3. Compiling on Windows

It is not necessary to modify the source code of CREST in order to change settings or basins. The control file with a default name of “control.txt” and basic grids dictate the necessary settings for running the model.

3.1 Using “Compaq Visual Fortran” (CVF) compiler

TODO: Write instructions here...

4. Control File Inputs

The model's input information is read in through the control file. This file dictates everything configurable about the way the CREST model operates. This includes input file locations, time periods over which to run, auto-calibration and output file settings.

There are nine parts to the control file (see example) and separated by a separate line like "********** Part X"

X here varies from A to I.

The other lines have two or more sections. The first section of each line (except separator line) is an explanation of this line; it can be changed into any other phrase (less than 80 letters) at the user's will.

4.1 Input File Information (Part A)

```
"   Project name"     "nzoia"
"        Run Style"   "simu"
"            Basic"   "biffit"      "D:\crest\project\example\"
"             Rain"   "trmmrt"      "D:\crest\project\example\trmmrt\"
"              PET"   "bibimo"      "D:\crest\project\example\bibimo\"
"           Export"   "biffit"      "D:\crest\project\example\export\"
"       Discharge"    "column"     "D:\crest\project\example\nzoia.hyp.txt"
```

The project name is "nzoia"; it appears in the output filename;

The run style "simu" means simulation; other possible run styles are "cali" (automatic calibration), "line" (on line mode) and some other debug modes.

Basic line shows the directory to search for DEM (digital elevation model), DDM (drainage direction map), FAM (flow accumulation map) and some other files; file format is set as "biffit" (binary format, same size as DEM), another choice is "ascfit" (ASCII format, same size as DEM) which is compatible to ARCGIS. ASCII format is compatible well between operation systems, but W/R speed is lower than binary format.

Rain line is the folder of precipitation data, the possible format are "trmmrt" (TRMM real time raw file), "trmmv6" (TRMM V6 raw file), "nmqbin" (NMQ Binary file), "biffit" and

“ascfit”.

PET line is the folder of potential evaporation data, the possible format are “bibimo” (binary format, bigger than DEM, monthly data), “biffit” and “ascfit”. “bibimo” is global monthly mean PET data include twelve files.

Export line is the folder of output files, the possible formats are “biffit” and “ascfit”.

Discharge line is the file of observation discharge used in automatic calibration; the file name can be blank unless the run style is “cali”. The possible format is “column” only.

4.2 Sub-basin Information (Part B)

```
" Sub basin Num"      1
"     Sub basin 1"      "Null"
```

Part B is used for basin-based parameter management; it is to be improved and better documented in a later version.

4.3 Run Time Information (Part C)

```
"        Time Step"    "h"       3
"       Date Begin"    "2003010100"    "no"
"        Date Warm"    "2001010100"
"        Date End"     "2003010200"    "no"
```

Second section of Time step line is unit of time steps, possible units in time step are “y” (year), “m” (month), “d” (day), “h” (hour), “u” (minute) and “s” (second). The last section of this line is the number of time steps. The example here means run the model runs with a 3 hour time step.

Date format in Date Begin line is defined as “yyyymmddhhuuss”, the length is up to the time step unit, for example, “yyyy” when time step unit is “y”; “yyyymmddhhuuss” when time step unit is “s”. The last section of this line is a mark for status reading, “yes” means user want to run the model by three 2-D status files as initial value, “no” means the initial values are determined by parameters. The 2-D status files are saved to and read from the Export folder if this setting is specified as "yes".

Date Warm only effective in automatic calibration, difference between simulation and observation discharge before this date will be omitted. A wrong Date Warm will be corrected automatically.

Format of Date End line is same as Date Begin line; the last section of this line is a mark for status writing.

4.4 Parameter Settings (Part D)

In total there are 17 parameters in this version. Each parameter has an abbreviation (the first section of each line), a minimum value (the second section of each line), a maximum value (the third section of each line) and a current value (the last section of each line). A "yes" or "no" mark tells whether optimize its value during automatic calibration. When calibrating the minimum and maximum values define the search range for each parameter and the current value is not used; when operating in simulation mode the minimum and maximum values are not used and the current value is used for the simulation run.

" Parameter Num"	18			
"coeM"	1	150	"yes"	107.67186
"expM"	0.2	0.9	"yes"	0.30501
"River"	0.1	3	"yes"	1.129872
"Under"	0.01	1	"yes"	0.869404
"LeakO"	0.1	1	"yes"	0.357427
"LeakI"	0.01	0.5	"yes"	0.119561
"Th"	10	100	"yes"	54.522789
"GM"	0.5	2	"yes"	1.259213
"pWm"	10	500	"yes"	337.073669
"pB"	0.05	1.5	"yes"	0.961943
"pIM"	0	100	"yes"	8.852914
"pKE"	0.1	3	"yes"	0.387291
"pFc"	1	10	"yes"	6.506332
"iWU"	1	100	"yes"	63.829159
"iSO"	1	10	"yes"	2.040005
"iSU"	1	50	"yes"	26.156597

"Rain"	0.1	3	"no"	1.0
"AreaC"	0.5	1.5	"no"	1.0

"coeM" refers to the slope flow speed multiplier. (pCoeM internally)

"expM" refers to the slope flow speed exponent. (pExpM internally)

"River" refers to the multiplier used to convert slope flow speed to channel flow speed. (pCoeR internally)

"**Under"** refers to the multiplier used to convert slope flow speed to interflow flow speed. (pCoeS internally)

"LeakO" refers to the overland reservoir discharge multiplier. (PLeaOne internally)

"LeakI" refers to the interflow reservoir discharge multiplier. (PLeaTwo internally)

"Th" refers to the flow accumulation needed for a cell to be marked as a channel cell. If a cells flow accumulation is greater than Th then the cells slope flow speed is multiplied by River. The units are km^2. (pTh internally)

"GM" refers to the change in DEM used for calculating the slope when the DEM for the downstream cell is higher than the upstream or the downstream cell is a nodata/outside region cell. (pGm internally)

"pWm" refers to the maximal soil water capacity (in depth) of three soil layers. (pWmax internally)

"pB" refers to the exponent of the variable infiltration curve. (pB internally)

"pIm" refers to the Impervious area ratio. This ratio is stored as a percentage between 0 and 100. (pIM internally)

"pKE" refers to the multiplier to convert between input PET and local actual ET. (pKE internally)

"pFc" refers to the soil saturated hydraulic conductivity. (pFc internally)

"iWU" refers to the initial value of soil water. This is a percentage of the pWm and should therefore vary between 0 and 100. (pOneW internally)

"iSO" refers to the initial value of overland reservoir. (pOneSto internally)

"iSU" refers to the initial value of interflow reservoir. (pTwoSto internally)

"Rain" refers to the multiplier on the precipitation field.

"AreaC" refers to the multiplier that modifies the area of grid cells. (Used for research and

debugging purposes)

4.5 Basin Outlets (Part E)

```
"    Exit Numbers"     1
"RCorLL, ClipRe"     "no"          "no"
"          Location"  "gauge"       34.08749     0.1208334
```

Currently the maximum number of allowed exits is 255; the name and location of each exit should be given on separate Location lines.

RCorLL specifies if the exit number is relative to the basic grids (DEM, DDM, FAM) or in latitude and longitude. A value of "yes" means the location of the exit is a column and row in the DEM, a value of "no" means the location is longitude and latitude.

If ClipRe is set as "yes", model will clip the drainage area for the first exit to help user check the drainage area or set a sub project from current project.

4.6 Calibration Settings (Part F)

```
"          Min NSCE"  0
" Max BiasP (%)"      100
"         Basic run"  100
"               Top N"  10
"          Criteria"  0.005
```

An adaptive random search algorithm is nested in CREST.

Min NSCE and Max BiasP (%) are used to screen out good parameters combinations from all randomly defined parameters combinations.

Basic run is the number of good parameters combinations (which meet the above NSCE and BiasP scores) to find before adapting the parameter span.

Top N is the number of parameter combinations to keep in order to adapt the parameter span.

Criteria value specifies that the automatic calibration will be finished when difference of NSCE between top N parameters combinations is less than this value.

4.7 Grid Outputs (Part G)

Part G is control of 2-D grid-based output, “yes” means output and “no” means do not output. The run time of the model depends on the number of outputs. A faster CREST model runtime can be achieved by reducing the number of outputs. Output format is controlled by the Export format in part A (see Section 4.1). All outputs are spatially interpolated to the proper resolution and clipped to either the basic grids or the drainage area depending on the setting of ClipRe in Part E (Section 4.5).

```
"              Rain"   "no"
"               PET"   "no"
"              actE"   "no"
"            Runoff"   "no"
"              Soil"   "no"
"            OneExc"   "no"
"            TwoExc"   "no"
"            OneSto"   "no"
"            TwoSto"   "no"
```

Rain is the input precipitation; unit is mm/hour.

PET is the input PET; unit is mm/hour.

actE is the depth of simulated actual evapotranspiration; unit is mm/hour.

Runoff is the simulated discharge of each grid cell; unit is m^3 /s.

Soil is the depth of water filling the pore space bucket "pWm"; unit is mm. This is also the “OneW” status output.

OneExc is the depth of surface excess rain; unit is mm/hour.

TwoExc is depth of interflow excess rain; unit is mm/hour.

OneSto is depth of overland reservoir; unit is mm/hour.

TwoSto id depth of interflow reservoir depth; unit is mm/hour.

4.8 Return Period Analysis (Part H)

Part H is control of flood level on grid based return period analysis. It’s not available in this

example.

" Level Num " 0

" Level Mark"

4.9 End of Control File (Part I)

Part I is an end of control file marker, the model will not read in anything after this part, this means the user can add comments after this line:

"End Mark Check" "eof"

5. Inputs

5.1 Basic Grids

The DEM (digital elevation model), DDM (drainage direction map), FAM (flow accumulation map) are the basic grids which define the region over which CREST will be able to model.

These can be derived using the supplied CNT Tool for sub-regions of the globe. The CNT Tool is able to resample and interpolate to any desired cell size for any user-defined region of the globe. All that is needed to use this tool is a bounding rectangle defined in terms of latitudes and longitudes for the region you wish to model.

5.2 Rain (QPE) Inputs

The rain input is one of two input forcings for the CREST model. Currently several input formats can be read by the CREST model. The formats and features are summarized in the table below.

Format	Generic	Match Basic Grids	Units	Naming Convention
trmmrt	No	No	mm/timemark	3B42RT. yyyymmddhh.6A.bin
trmmv6	No	No	mm/timemark	3B42.yymmddhhdd.6A.HDF
nmqbin	No	No	mm/timemark	1HRAD.HSR. yyyymmdd.hh00
ascfit	Yes	Yes	mm/timemark	yyyymmddhhuuss.txt
ascbig	Yes	No	mm/timemark	yyyymmddhhuuss.txt
biffit	Yes	Yes	mm/timemark	yyyymmddhhuuss.bif

5.3 PET Inputs

The Potential Evapotranspiration (PET) is the second input forcing for the CREST model.

6. Run Styles

Different run styles have different possible outputs; the table below lists possible outputs for each run style:

	simu	cali	online
2-D Output	Yes	No	Yes
Regional Mean Values	One	Multiple	One
Reads Status Files	Yes	Yes	Automatically
Writes Status Files	Yes	No	Automatically
Parameter Combinations	No	Yes	No

6.1 Simulation

6.1.1 Running in Simulation Mode

To run the model in simulation mode the run style in the control file must be set to "simu". Precipitation data and PET data are also needed for the simulation period. By default CREST reads the control file called "control.txt" located in the current working directory. However, as of CREST 1.6c it is possible to specify the control file name as a command line option to the CREST executable.

6.1.2 Simulation Mode Standard Output

```
 CREST V1.5
 anso         104          43  0.4300000       15.68800       3345.000
 anso   617996.6     km^2
 Kernal
2003010100
2003010103
2003010106
2003010109
2003010112
2003010115    Rain File Missed
2003010118
2003010121
2003010200
 NaN            NaN
 CREST V1.5 Finished
```

The first line is model version message.

The second line includes Exit Name, Col, Row, Longitude, Latitude and total drainage grids,

The third line is name of first exit and its simulated drainage area from DEM and DDM.

The third line is name of kernel model used here (combination of rainfall-runoff and routing models)

The last but one line is statistic (NSCE and BiasP) between simulation in first exit and observation.

The last line is a succeed mark

The others are information of each step following rules of “no message means good message”.

6.1.3 Simulation Mode File Output

Besides any possible 2-D files, one file in export folder will be found after run the model in “simu”; the name is defined as: “Project name”.“simu”.“finished time”.“txt”, like file “nzoia.Simu.20091130155202.txt” in the example. It’s a time series of regional mean values include eleven or more columns: Date, Rain, PET, actE, Soil, OneExc, TwoExc, OneSto, TwoSto, nzoia, Gauge.

The first column Date is date and time, the format is defined as “yyyymmddhhuuss”, the length is determined by time step unit (see Section 4.3).

The last column Gauge is from observation discharge. CREST will not do any temporal interpolation for discharge data, missing data is marked as “-1”.

Meaning of other columns is similar to what is defined in Section 4.7.

Column nzoia is the simulated discharge at the exit grid, the number and location is defined part E (Section 4.5).

6.2 Automatic Calibration

6.2.1 Running in Automatic Calibration Mode

To run the model in automatic calibration mode the run style in the control file must be set to "cali". Precipitation data, PET data and observed discharge (Section 4.1, Discharge) are also needed for the calibration period. Resumption of calibration has been implemented in CREST v1.6b. A saved information file called "savedParams.cali" is written to the Export folder and will be read automatically on calibration startup if it exists.

6.2.2 Automatic Calibration Mode Standard Output

```
 CREST V1.5
 nzoia          17          140   34.08749      0.1208334       14710.00
200912021107          1
200912021107          2
200912021107          3
200912021107          4
200912021107          5
200912021107          6
200912021107          7
200912021107          8
200912021107          9
200912021107         10           1  0.003395  -25.5535  0.003395
200912021107         11
200912021107         12
200912021107         13
200912021107         14
200912021107         15
```

The first line is model version message.

The second line includes Exit Name, Col, Row, Longitude, Latitude and total drainage grids.

Lines after that is finished time of each run following a run number. Once CREST found any good parameters combinations, it will show you the index, NSCE, BiasP and gap of top N good

results.

6.2.3 Automatic Calibration Mode File Output

In “cali” model, the model will not output any 2-D files automatically. One specially output is named “Project name”.“cali”.“begin time”.“txt”, such as “nzoia.Cali.20091130155417.txt”. the file include 21 columns, NSCE, Bias, 17 Parameters, Index, Run Num.

NSCE and Bias are statistic values between discharge of the first exit (see Section 4.5) and observation

17 Parameters are 17 separate columns list the parameter values.

Index is a number of good parameters combinations.

Run Num is total number of runs before found that good parameters combinations. It can be used in the appraising the parameter setting of your automatic calibration.

If automatic calibration is finished without any problem, the top N parameters combinations will be added into the end of this file.

Besides that file, there also some other outputs named “Project name”.“cali”.“begin time”. “Index”.“txt”, such as “nzoia.Cali.20091130155417.3826.txt”. The format of these files are same as in Section 6.1.3.

6.3 Online mode

In online mode, CREST will scan the latest precipitation file from now as the Date End, and the latest status file from the found Date End as the Date Begin. If user defined the Date End in control file earlier than present in purpose, the model will scan from that earlier time. If used in any project with predicted precipitation, we need change the code. If no new precipitation file has been found, the model will terminate. If no old status file has been found, the model will run from Date Begin defined in control file.

There is one main output in online mode named “Project name”.“line”.“txt”, such as “nzoia.Line.txt”. The format of this file is same as Chapter 4.1. New result will be appended into this file, and make it same as from one run.

Status files are very important to connecting different runs; each run will generate three status files once one or more precipitation files have been detected. Status files are named as

“Project name”.“Status”.“date and time”.“OneW/OneSto/TwoSto”.“bif”, they are compressed binary file such as “nzoia.Status.2003011100.OneW.bif”.

Online run need regular maintenance to clean old status files, the frequency is up to your storage.

7. Implementing of the CREST model for other basins

The CREST model automatically runs over the region defined by the basic grid files. Therefore if you are operating with global basic grids it is possible easily and quickly model an basin in the world by defining a new basin outlet as described in Section 4.5. In the event that the basic grids you are using do not cover the region which you want to model or if you want to model a region with a finer resolution then it is necessary to derive new basic grids. The steps to do this are described below.

Fully implementing the CREST model on any basin can be achieved in a three step process:

1. To implement the CREST model on another basin it is first necessary to derive the basic grids for the new basin region.
    - **a.** Determine the latitudes and longitudes of a rectangle around the region which you wish to model. These do not have to be precise by any means and can be pulled from Google Earth or Google Maps for an approximate region around the basin you wish to model. **The basin you wish the model on must be entirely contained inside the bounding rectangle you specify however.**
    - b. Derive the basic grids (DEM, DDM, FAM) using the supplied CNT Tool.
2. A control file for the new modeling region needs to be created.
    - a. Copy an existing control file (even one of the provided example control files) and modify the paths to point to the location of the new basic grids.
    - b. It is likely that the CNT Tool produced DEM, DDM, and FAM grids that were NOT named appropriately. In order for CREST to work with the DEM, DDM and FAM files produced by the CNT Tool they must be named DEM.txt, DDM.txt and FAM.txt. It is important to change the file format in the control file for the basic grids to "ascfit" (see Section 4.1 for more details). After the initial run with the newly provided ascii basic grids CREST will produce bif binary grids. At this point the file format in the control file for the basic grids

can be changed to "biffit" for faster model spinup times.

c. At this point new basin outlets inside the modeling region can be defined as described in Section 4.5.

3. The model can now be run for your new basin in any desired mode. To get realistic results it is necessary to calibrate the model using a gauged station located near your new basin's outlet. The automatic calibration built into the CREST model is the easiest way to calibrate the model.

8. Improvement and help

Future work:

Fix the bug when using *gfortran* compiler

Improve the date manage engine

Fix bugs in automatic calibration output

Enhance performance for peak automatic calibration

Improve routing subroutine for future possible upgrade

Improve basin based parameter management.

Development and maintenance of the current official version of the NASA-OU CREST model is conducted at the University of Oklahoma, Remote Sensing and Hydrology Research Group (http://hydro.ou.edu) and Center for Natural Hazard and Disaster Research located in National Weather Center (http://nwc.ou.edu). For information about the current release of the CREST model or to get the source code for beta versions of releases under development, send e-mail to yanghong@ou.edu and include "CREST Model" in the subject line.